Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol

Appendix J:
Power Analysis for Annual Trend Detection in Climate Variables for Oregon Caves and Lava Beds National Monuments Caves Protocol

Version 1.0

Revision History Log

Previous Version	Revision Date	Author	Changes Made	Reason for Change	New Version

This document contains the power analyses for climate variables in the two parks (Oregon Caves National Monument and Lava Beds National Monument) covered by the Klamath Network's cave protocol.

Power Analysis for Annual Trend Detection in Climate Variables for ORCA and LABE Caves Protocol

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*Steve Hayes assisted with organizing the data from LABE for use in this report.

Introduction

The following questions are addressed in this report to inform the sampling design choices for monitoring Oregon Caves National Monument (ORCA) and Lava Beds National Monument (LABE) climate variables; specifically, annual relative humidity (%) and annual temperature (Celsius):

1) How many data loggers are needed in ORCA to determine annual trends in temperature and relative humidity for the cave? How many years are needed to detect annual trends in both parameters?

2) How many caves are needed in LABE to monitor park-wide annual trends in temperature and relative humidity for each zone (deep, middle, entrance, outside)? How many years are needed to detect annual trends in both parameters?

These questions are addressed by a power analysis based on the current available pilot data from both parks. The annual magnitude of trend investigated for relative humidity and temperature are based on input from Jean Krejca with Zara Environmental, Inc., Daniel Sarr and Sean Mohren of KLMN. In terms of a power analysis, I specify the Type 1 error to 10% and investigate a range of sample sizes and years to detect varying magnitudes of annual trend. I assume the mixed linear model for trend proposed in Urquhart et al. 1993 is appropriate for analyzing future KLMN caves climate data. This model is quite flexible and can accommodate the different types of sampling units and sampled populations in ORCA and LABE. The main difference is the scope of statistical (model-based) inference is different for the two parks. At ORCA, we are interested in annual trends within one cave, whereas at LABE we are interested in park-wide annual trends encompassing multiple caves.

Proposed Sampling Designs

At LABE 31 caves were randomly selected with unequal probability from a population of 59 caves using GRTS. For each selected cave, 1 HOBO logger will be located within one of four strata (deep zone, middle zone, entrance zone, outside zone). Four loggers will be used in 31 caves for a total of 124 loggers in LABE. The caves were selected with unequal probability because 6 caves with known bats and 5 caves with ice were selected with probability 1; the remaining 20 caves were selected with probability equal to 0.53. The sampling unit is a cave and the sampled and target population is the 59 pre-selected caves located in LABE. Therefore within this park we are interested in annual park-wide trends in temperature and relative humidity of these 59 caves.

At ORCA there is one cave of interest; currently, 23 HOBO loggers will be randomly located throughout the cave. For ORCA the sampling unit is a location within the cave where the HOBO is placed; thus the scope of inference is in terms of the annual trend in the one cave. Also, data loggers will be placed in the deep, middle, entrance, and outside zones (1 logger each zone) in Blind Leads Cave within ORCA.

For both parks, the loggers will be gathering hourly data on temperature and relative humidity. The data will be downloaded three times a year. In terms of a trend analysis we compute an annual estimate for each HOBO based on averaging over hours, days, and months. This is reasonable for an annual trend power analysis; however, this does not preclude the parks from investigating seasonal patterns in the climate data once it is available. Or using a control chart approach to track trends for each cave separately once a reasonable baseline is established (Morrison 2009).

Power Analysis for Trend Detection

In order to perform a power analysis for univariate trend, a model must be assumed for the future data. I adopt the linear model presented in Urquhart and Kincaid (1999); Larsen et. al (2001); Kincaid et. al (2004); and Urquhart et. al (1993). The model is as follows where is the observed characteristic of interest (e.g., temperature) for site *i* in year *j*, , , ,and the components are assumed independent. There have been many modifications to this general model idea that allow for varying trends for each site (Piepho and Ogutu, 2002, Van-Leeuwen et al. 1996). However, given the scarcity of pilot data particularly for LABE I used a model assuming trends over time to not vary by site. I used the functions written by Tom Kincaid to estimate power based on model above, for specific details refer to the paper by Urquhart et al 1993. These are *estimates* of the power because we are estimating the variance components. These estimates can be improved once more sampling is conducted within LABE.

For LABE the model is used separately for the different zones, so the site = a cave; whereas for ORCA the site is simply a logger location.

Pilot Data

The data used to estimate the necessary variance components was provided by Sean Mohren KLMN via Elizabeth Hale and John Roth (ORCA) and Shawn Thomas (?) (LABE).

The available climate data for LABE is summarized in Table 1. HOBO data is available from Caldwell Cave January 25 through February 25, 2010; Wishbone Cave January 25 through February 25, 2010; and Catacombs Cave February 16 through March 3, 2010 for the 4 different zones of interest. The complication is based on this data we have no estimate of temporal variation in yearly averages and the site-to-site variance is based on only 3 caves.

A longer time series of temperature and relative humidity is available for both Craig cave and Angleworm cave for the “middle zone” for the months of January and February in the years 2000-2002. Also, data from a weather station is available for 2006 to 2010 in the months of January, February, and March. These datasets can be used to estimate the temporal variance component for the middle and outside zones. One thing to bear in mind is that across the different caves the definition of a zone may vary due to the variety of cave architecture. For example, a middle zone in one cave may be much further from the entrance than a middle zone in another cave; statistically, this results in greater variation among caves within a zone. The data used for estimating the variance components are presented in Figures 1 and 2. One major issue is that we are assuming that the average of the Jan-Feb (sometimes March for outside zone) data is representative of the annual average in Temperature and Relative Humidity.

	Year							
Zone	**2000**	**2001**	**2002**	**2006**	**2007**	**2008**	**2009**	**2010**
Deep	0	0	0	0	0	0	0	3
Entrance	0	0	0	0	0	0	0	3
Middle	2	2	2	0	0	0	0	3
Outside	0	0	0	1	1	1	1	4

Table 1. Summary of pilot data available for the different cave zones within LABE. The number corresponds to the number of caves sampled for a given year and zone.

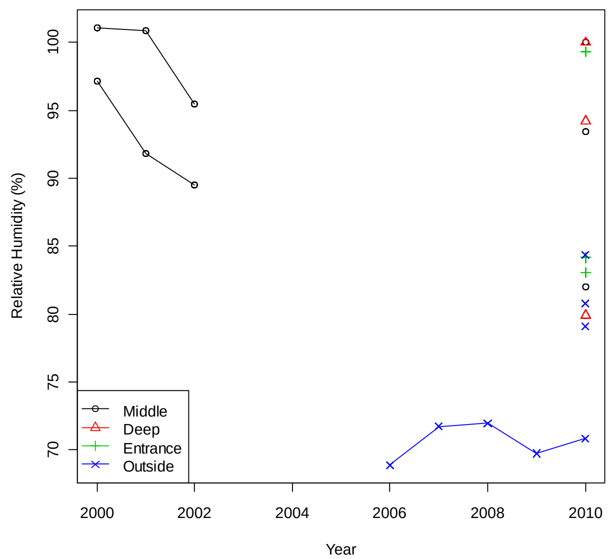

Figure 1. LABE relative humidity annual averages, the sample sizes for the year and zone combinations are in Table 1.

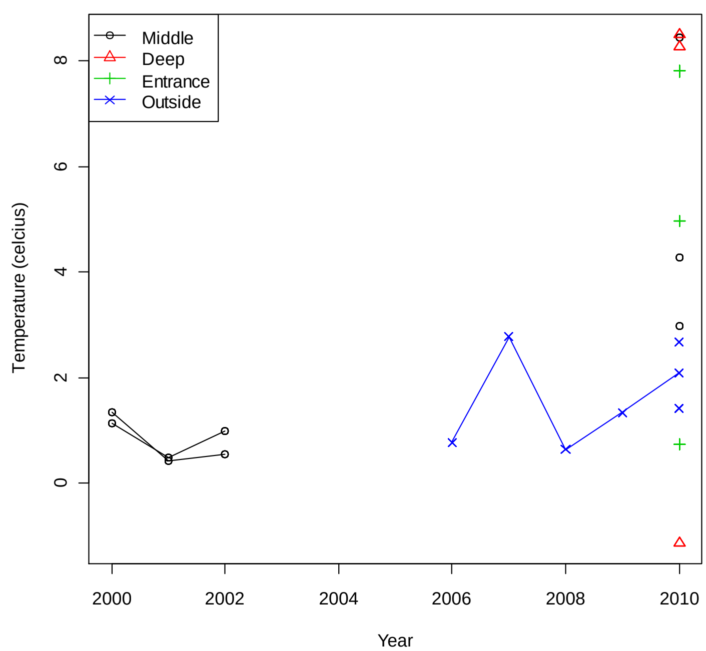

Figure 2. LABE annual average Temperatures (Celsius) for each zone-year combination.

ORCA has more pilot data available. There were 12 locations with relatively continuous measurements of relative humidity and temperature for the years 2007 to 2010. The monthly data are presented in the Appendix. Based on the data in Figure 3 and 4 we can estimate the site, year, and site*year variance components for the power analysis for ORCA.

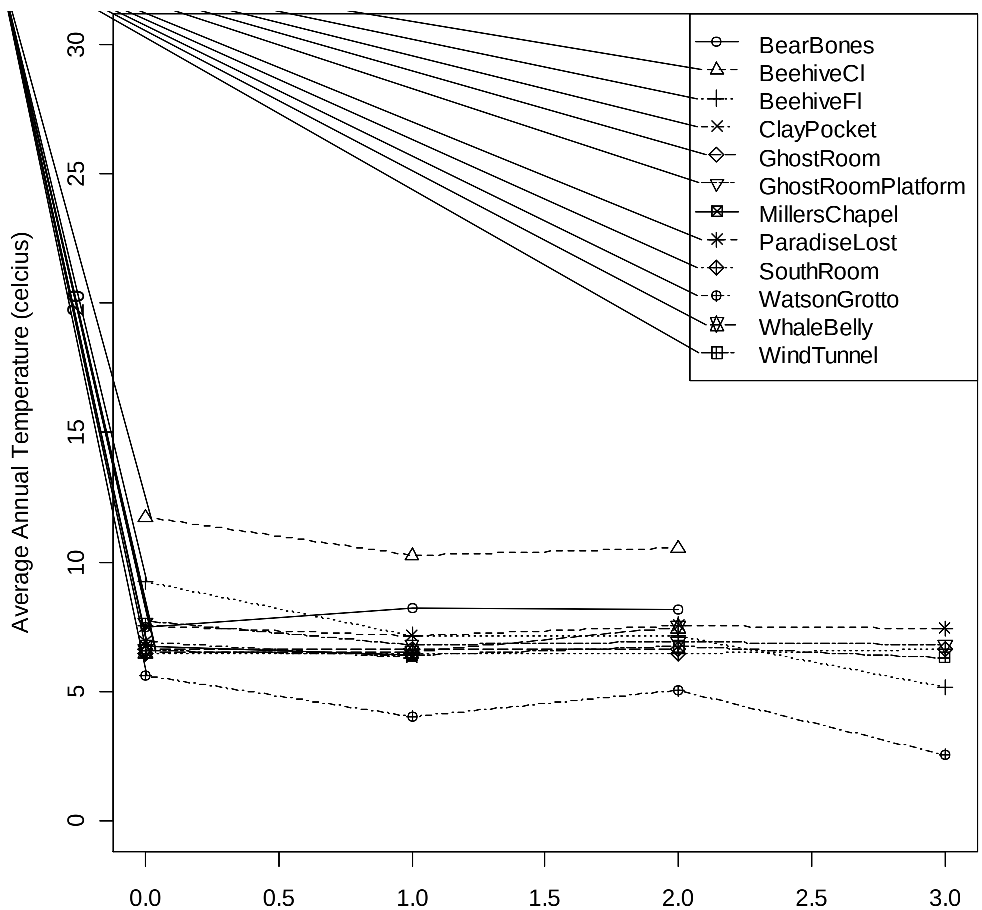

Figure 3. ORCA average annual temperature (Celcius) for 12 different locations within the cave for 2007-2010.

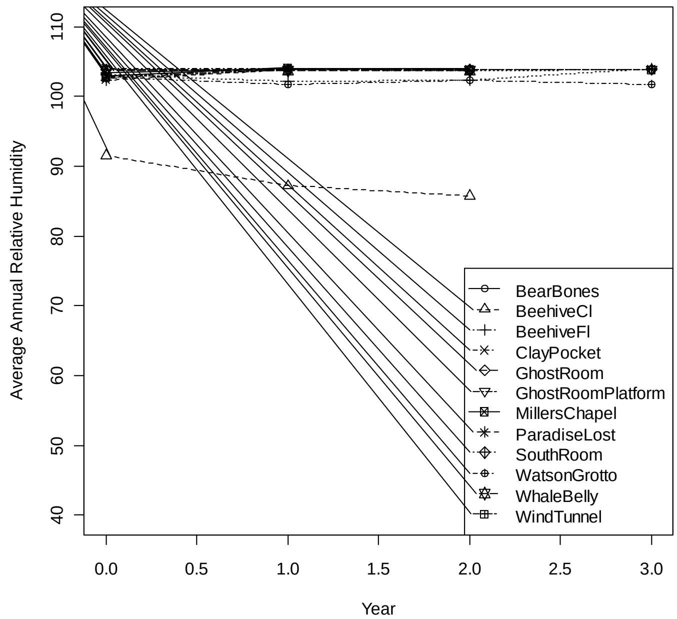

Figure 4. ORCA average annual relative humidity for 12 different locations within the cave for 2007-2010.

Variance Components Estimates

I used the lmer function in the lme4 package in the *R* freeware statistical platform to estimate the random and fixed components of the mixed model using restricted maximum likelihood (REML). The estimated variance components are displayed in Table 2 for Temperature and Relative Humidity for ORCA and Table 3 for LABE.

Response	**Parameter**	**Estimate**
Temperature		1.95
		0.19
		0.45
	μ	6.94
Relative Humidity		19.52
		0
		0.92
	μ	102.21

Table 2 Estimated Variance Components and fixed effects using REML for ORCA, the untransformed response variable was used.

			Zone	
Relative Humidity		**Middle**		**Outside**
		48.57		32.67
		8.56		1.7
		3.46		0.00029
	μ	93.83		78.56
Temperature (celcius)				
		9.67		~0
		0.13		0.34
		0.05		0.41
	μ	3.43		1.54

Table 3 Estimated Variance Components and fixed effects using REML for LABE, the untransformed response variable was used. Only 2 zones were used because of the severe scarcity of data.

Results

The values in Table 2 and 3 were used as inputs into the function written by Tom Kincaid, EPA Statistician for estimating power for detecting trends. The assumed revisit design is an always revisit design, assuming once caves or locations are selected the HOBO placement does not change over time.

ORCA

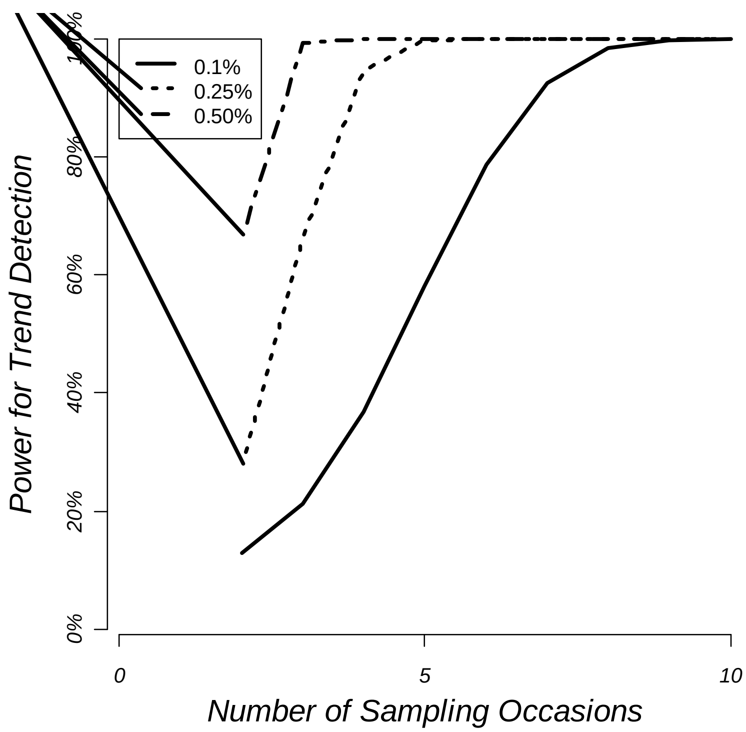

Figure 5. Estimated power for detecting annual change in relative humidity over 10 years for 30 fixed locations in ORCA. The annul change of 0.1%, 0.25%, and 0.50% correspond to 1, 2.5, and 5 net change in relative humidity after 10 years.

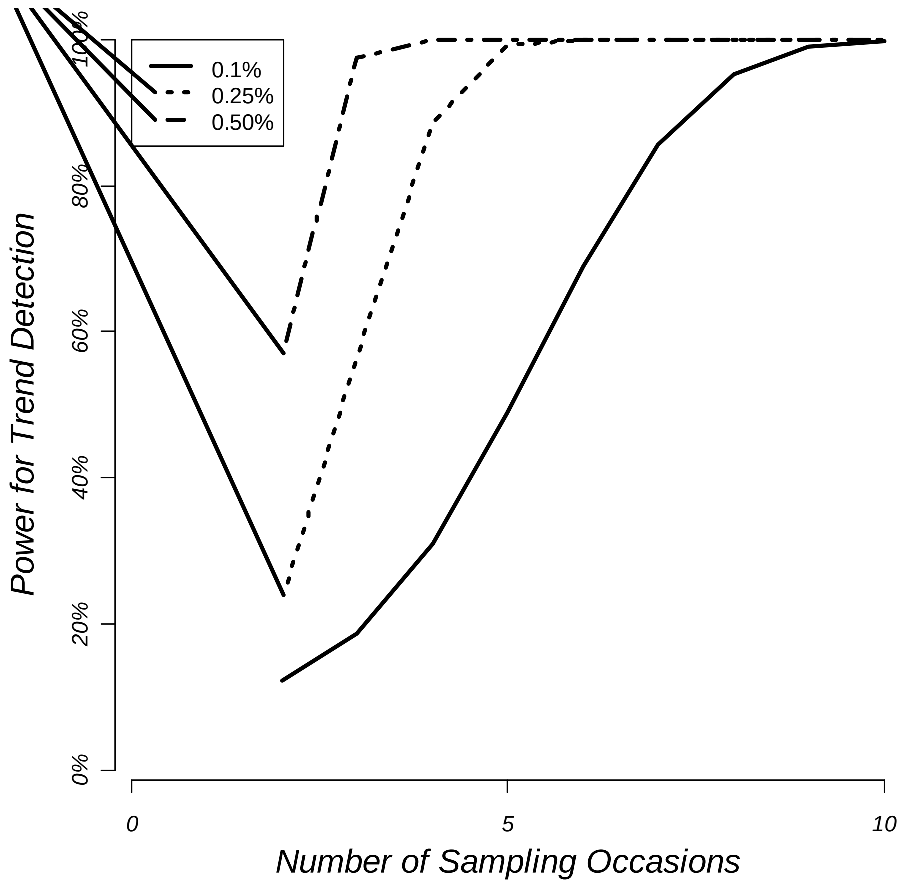

Figure 6. Estimated power for detecting annual change in relative humidity over 10 years for 23 fixed locations in ORCA. The annul change of 0.1%, 0.25%, and 0.50% correspond to 1, 2.5, and 5 net change in relative humidity after 10 years.

The usual desired 80% power to detect a net change of 1% in relative humidity after 10 years will be reached around 7 years for a sample size of 30 HOBO loggers with Type 1 error of 10%. This is a relatively conservative change based on the pilot data in Figure 4, there is little fluctuation in relative humidity for the three years of sampling. A larger net change of 5% would be detected after only 3 or so years of sampling with 80% power and 10% Type 1 error. Based on the estimated variance components, it appears that using 23 data loggers is sufficient to detect annual trends in relative humidity in the cave (Figure 6). However, the biggest assumption is that the pilot data adequately represents both the spatial and temporal variation of relative humidity within the cave.

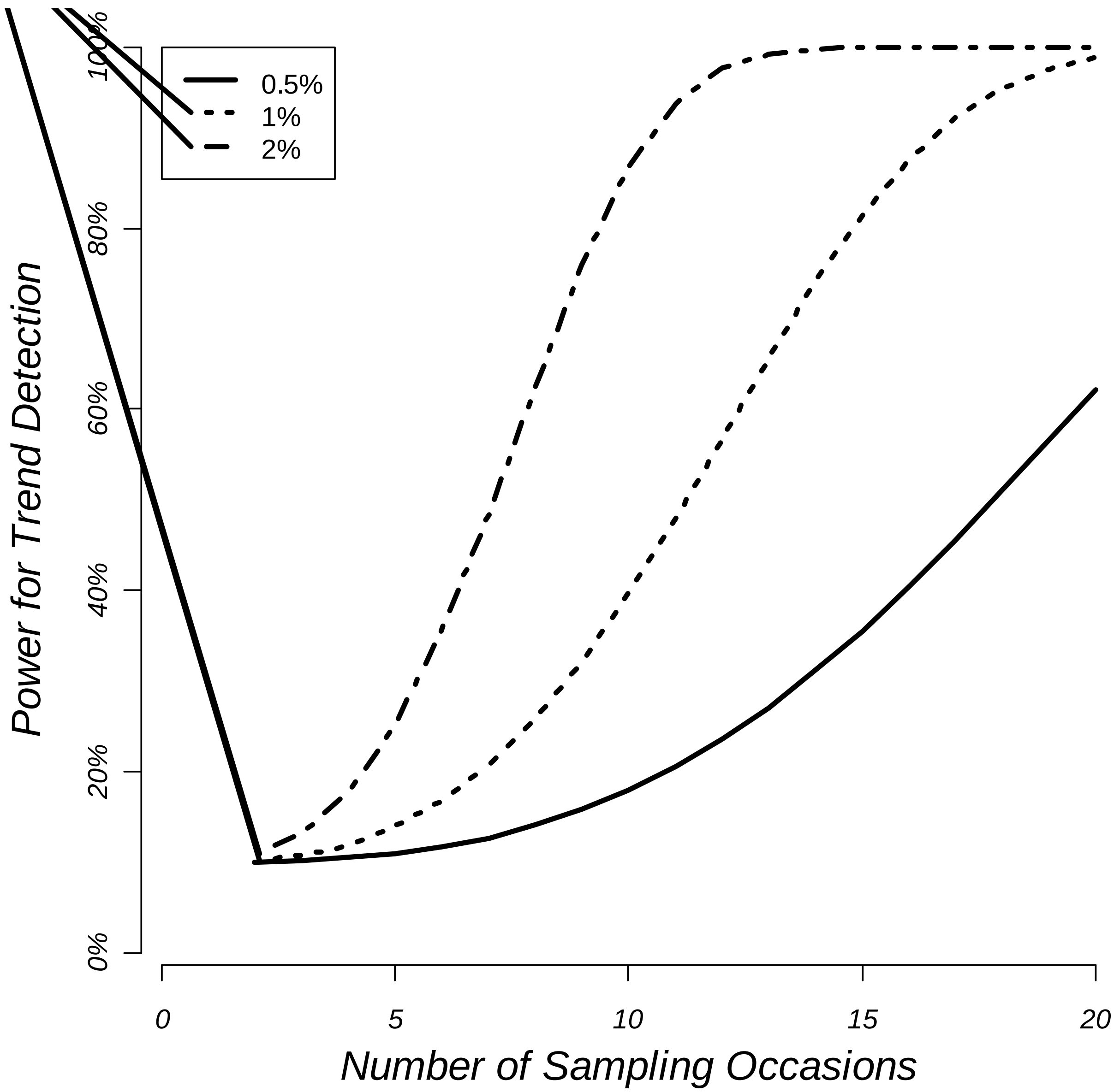

Figure 7. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 23 fixed locations in ORCA. The annual change of 0.5%, 1%, and 2% correspond to 0.69, 1.39, and 2.78 Celsius net change in temperature after 20 years.

In terms of detecting trends in annual temperature measurements, Figure 7 suggests that 80% power will be achieved after ~8 years of sampling for a 2.78 net change in temperature after 10 years. However, for a smaller 0.5% annual change in temperature power is only 60% after 20 years of sampling, increasing to 30 or 40 HOBOs does not improve the power (not shown). Presumably, power will increase as the number of years sampled increases.

LABE

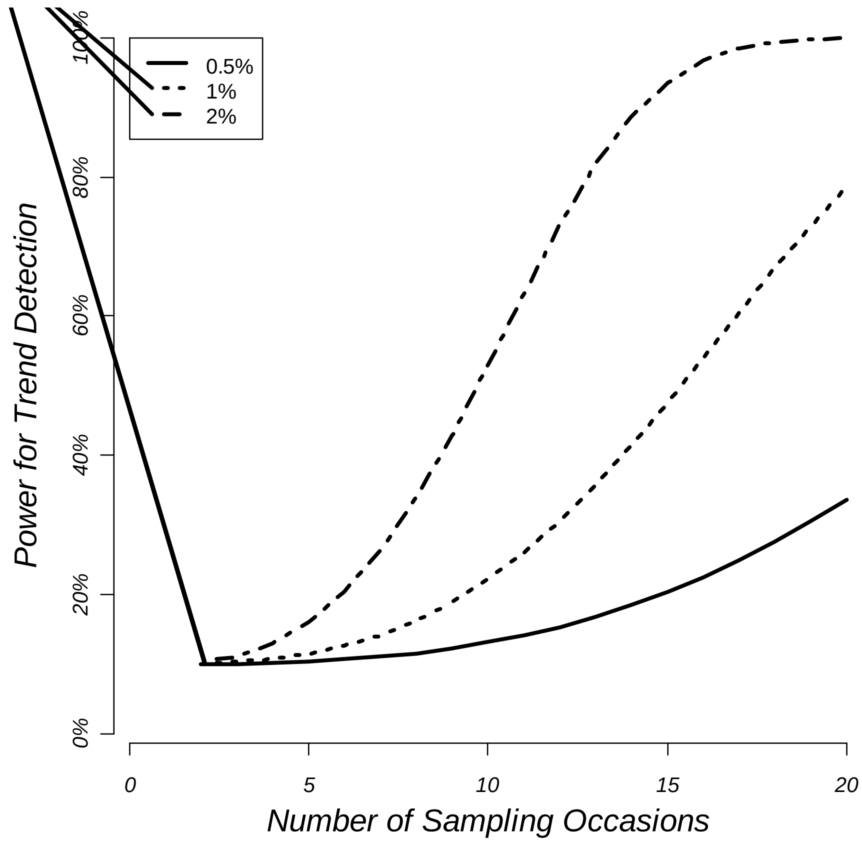

Figure 8. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 30 fixed caves in LABE for the middle zone. The annual change of 0.5%, 1%, and 2% correspond to 0.343, 0.69, 1.37 Celsius net change in temperature after 20 years.

For LABE, 80% power to detect annual trends in temperature in the middle zone will be achieved after ~12 years for a 2% annual change and 20 years for a smaller 1% change (Figure 8). For a 0.5% annual change ~35 years of sampling is needed to achieve 80% power for 30 caves, increasing the number of caves to 60 does not change the power to detect trends. To increase the power to detect trends in annual temperature in the middle zone increasing the number of years is more important than increasing the number of caves surveyed.

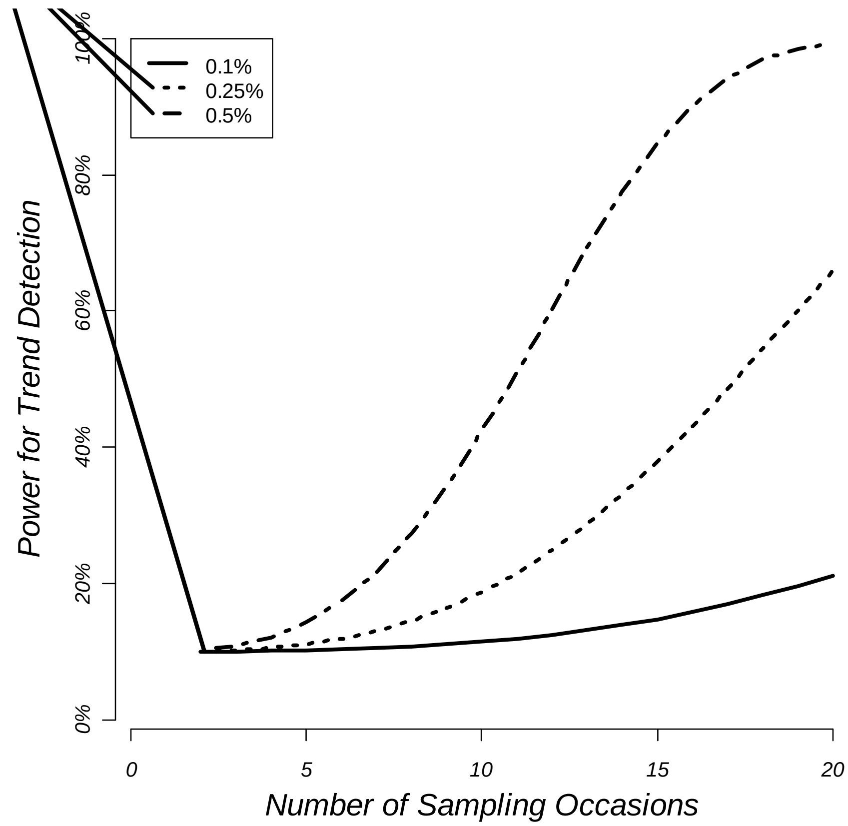

Figure 9. Estimated power for detecting annual change in relative humidity over 20 years for 30 fixed caves in LABE for the middle zone. The annul change of 0.1%, 0.25%, and 0.5% correspond to 1.88, 4.69, and 9.38 net change in relative humidity after 20 years.

For the annual trends in relative humidity within the middle zone, a similar pattern emerges in that for a small annual change of 0.1% >40 years are needed to achieve 80% power, increasing the number of caves does not substantially increase power for the smaller annual change. However, for the larger annual change of .5% corresponding to a net change of 9.38 in average annual relative humidity 80% power is reached after 15 years for 30 caves.

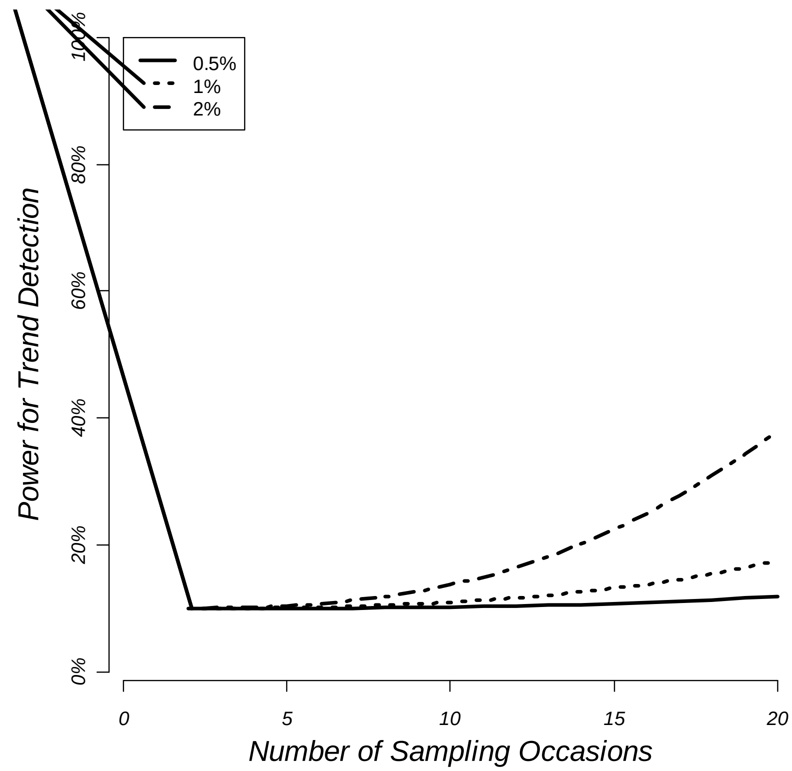

Figure 10. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 30 fixed caves in LABE for the outside zone. The annul change of 0.5%, 1%, and 2% correspond to 0.154, 0.308, 0.616 Celsius net change in temperature after 20 years.

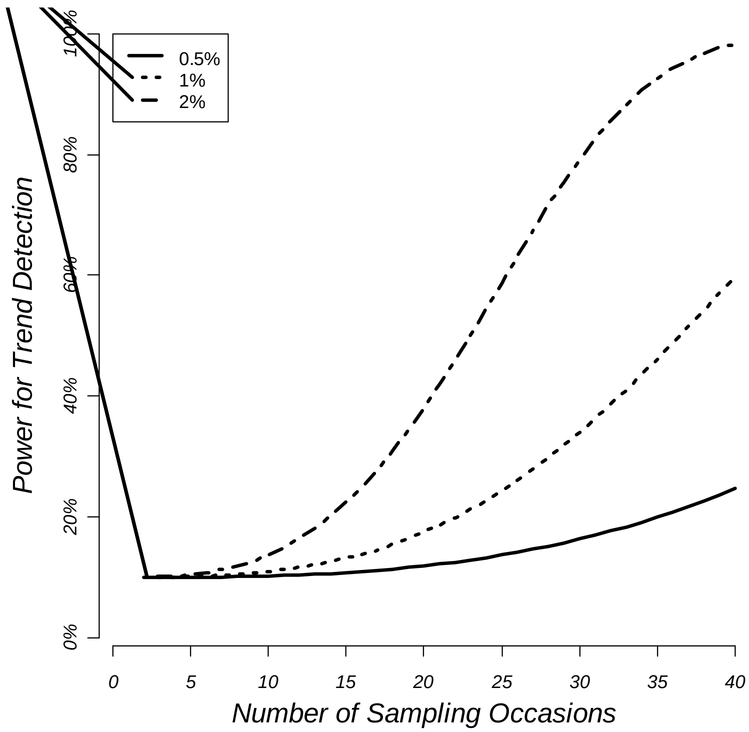

Figure 11. Estimated power for detecting annual change in temperature (Celsius) over 40 years for 30 fixed caves in LABE for the outside zone. The annul change of 0.5%, 1%, and 2% correspond to 0.308, 0.616, 1.232 Celsius net change in temperature after 40 years.

The power is substantially lower for the outside zone for detecting annual trends in temperature (Figure 10). Reasonable power is achieved for detecting a 1.23 net change in annual temperature after 40 years with only 30 caves (Figure 11).

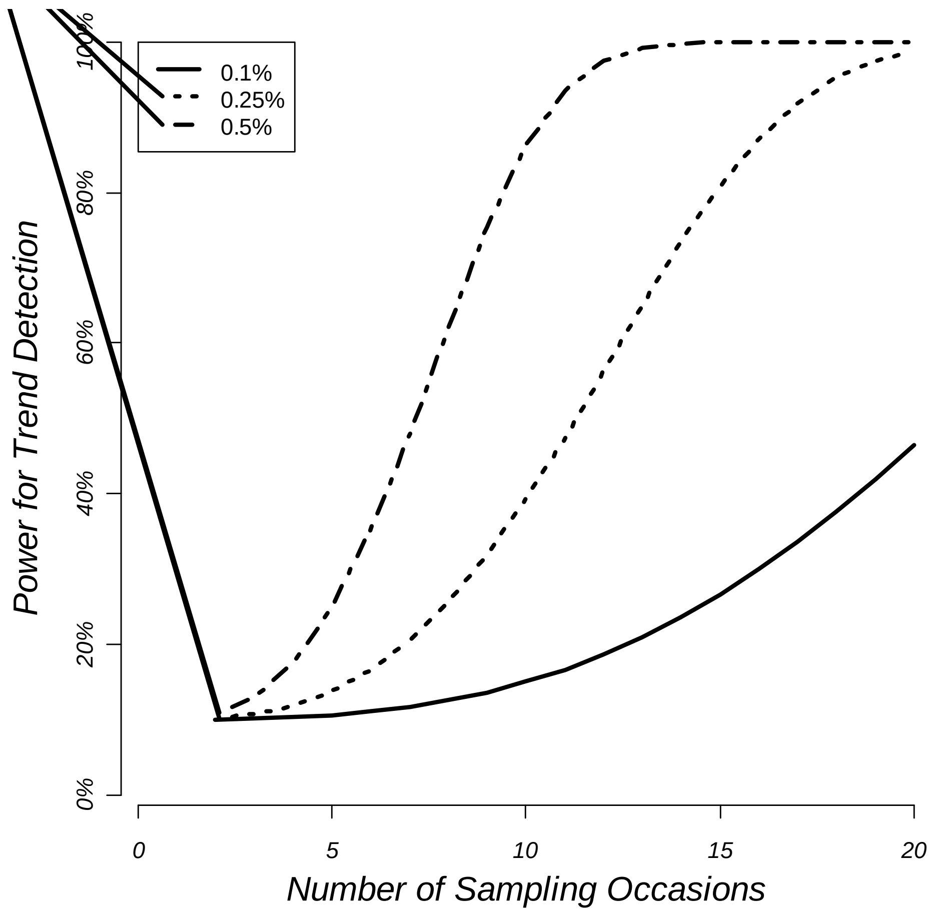

Figure 12. Estimated power for detecting annual change in relative humidity over 20 years for 30 fixed caves in LABE for the outside zone. The annul change of 0.1%, 0.25%, and 0.5% correspond to a net change in relative humidity after 20 years of 1.57, 3.93, and 7.86.

In terms of trends in relative humidity in the outside zone, 30 caves sampled for 20 years results in >80% power for a 7.86 net change in relative humidity after ~8 years of sampling. For a smaller net change of 3.93 after 20 years >80% power is reached after around 15 years of sampling with 30 caves.

Conclusions

Assuming that the pilot data adequately represents the spatial and temporal variation within the ORCA cave, using 23 data loggers is sufficient to monitor annual trends in relative humidity and temperature. For LABE, assuming the pilot data adequately represents the cave-to-cave variability and the temporal variation in relative humidity and temperature, the proposed sampling of 30 caves for the outside and middle zones should be adequate with enough years of monitoring.

References

Kincaid, T. K., Larsen, D. P., and Urquhart, N. S. (2004). The structure of variations and its influence on the estimation of status: indicators of condition of lakes in Northeast, U.S.A. Environmental Monitoring and Assessment, 98(12):1–21.

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Larsen, D. P., Kincaid, T. K., Jacobs, S. E., and Urquhart, N. S. (2001). Designs for evaluating local and regional scale trends. Bioscience, 51(12):1069–1078.

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Piepho, H.-P. and Ogutu, J. O. (2002). A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics, 7(7):350–360.

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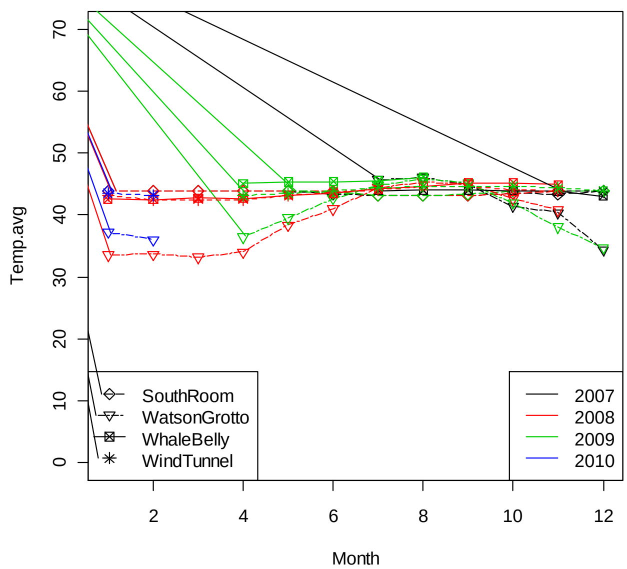
Urquhart, N. S., Overton, W. S., and Birkes, D. S. (1993). Comparing sampling designs for monitoring ecological status and trends: Impact of temporal patterns. *Statistics for the Environment,* V. Barnett and K.F. Turkman, eds. John Wiley and Sons Ltd.

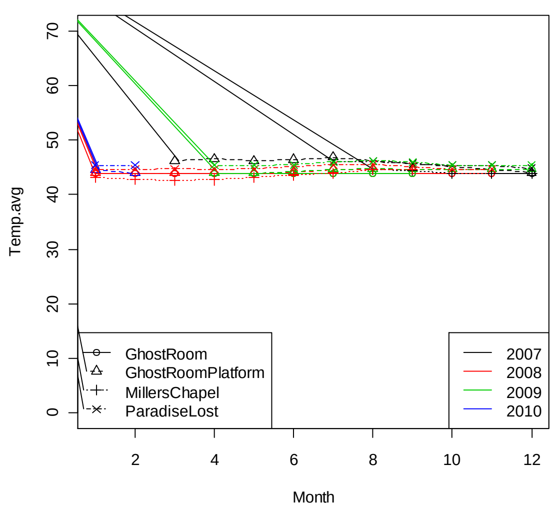
VanLeeuwen, D. M., Murray, L. W., and Urquhart, N. S. (2002). A mixed model for both fixed and random trend components across time. Journal of Agricultural, Biological, and Environmental Statistics, 1(4):435–453.

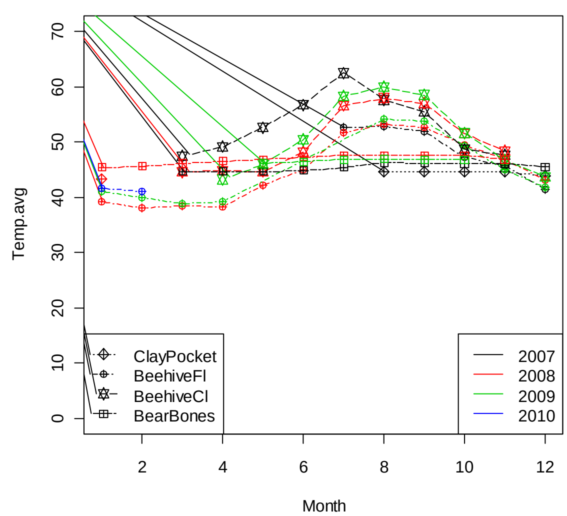
Appendix: ORCA Monthly Climate Data

Temperature

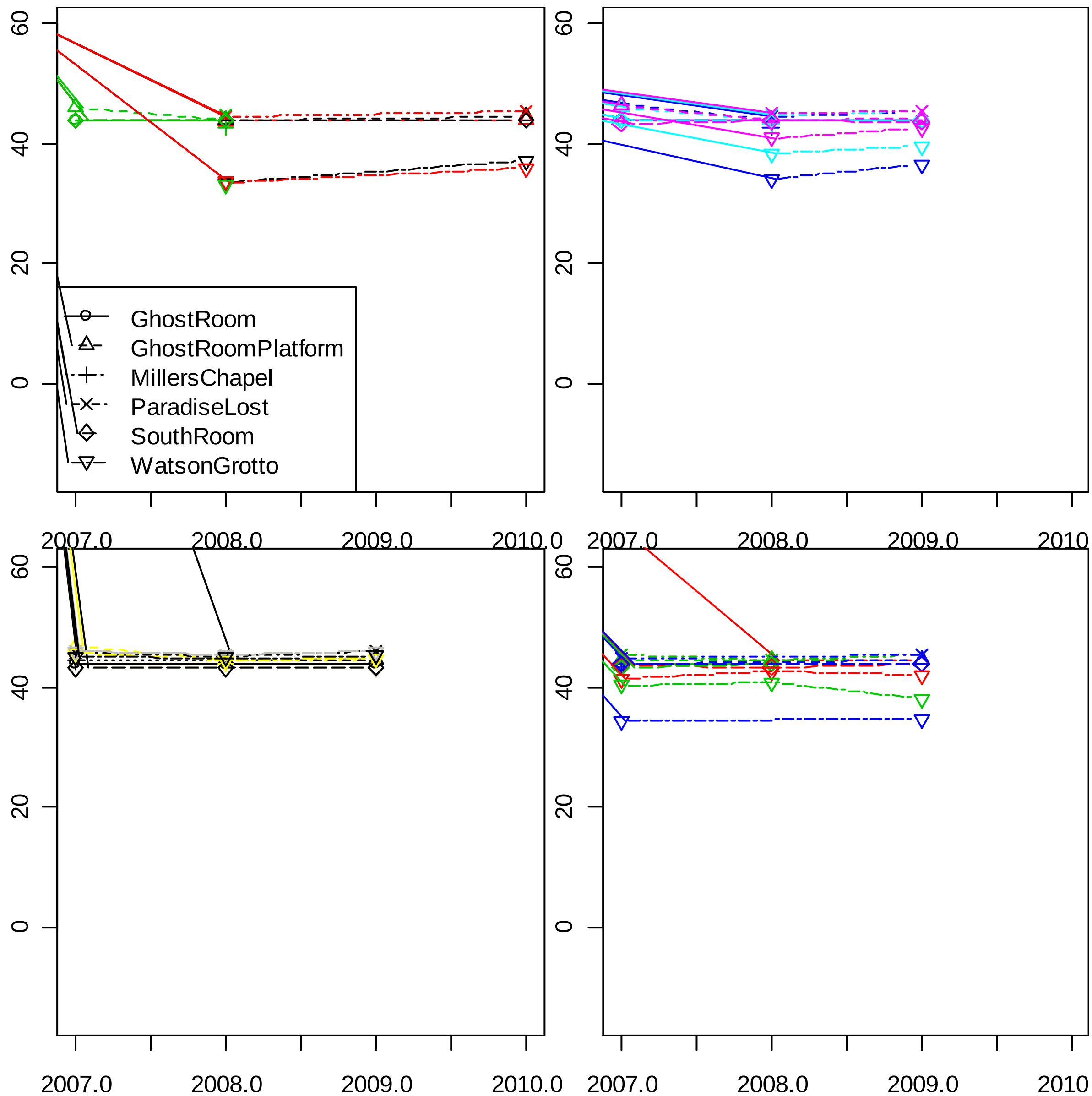
The Monthly averages (averaged over hours and days) for each location plotted for each year separately; there doesn't appear to be much month-to-month variability except for Watson Grotto, Beehive ceiling, and beehive floor locations. The patterns are basically the same across the 4 years of data.

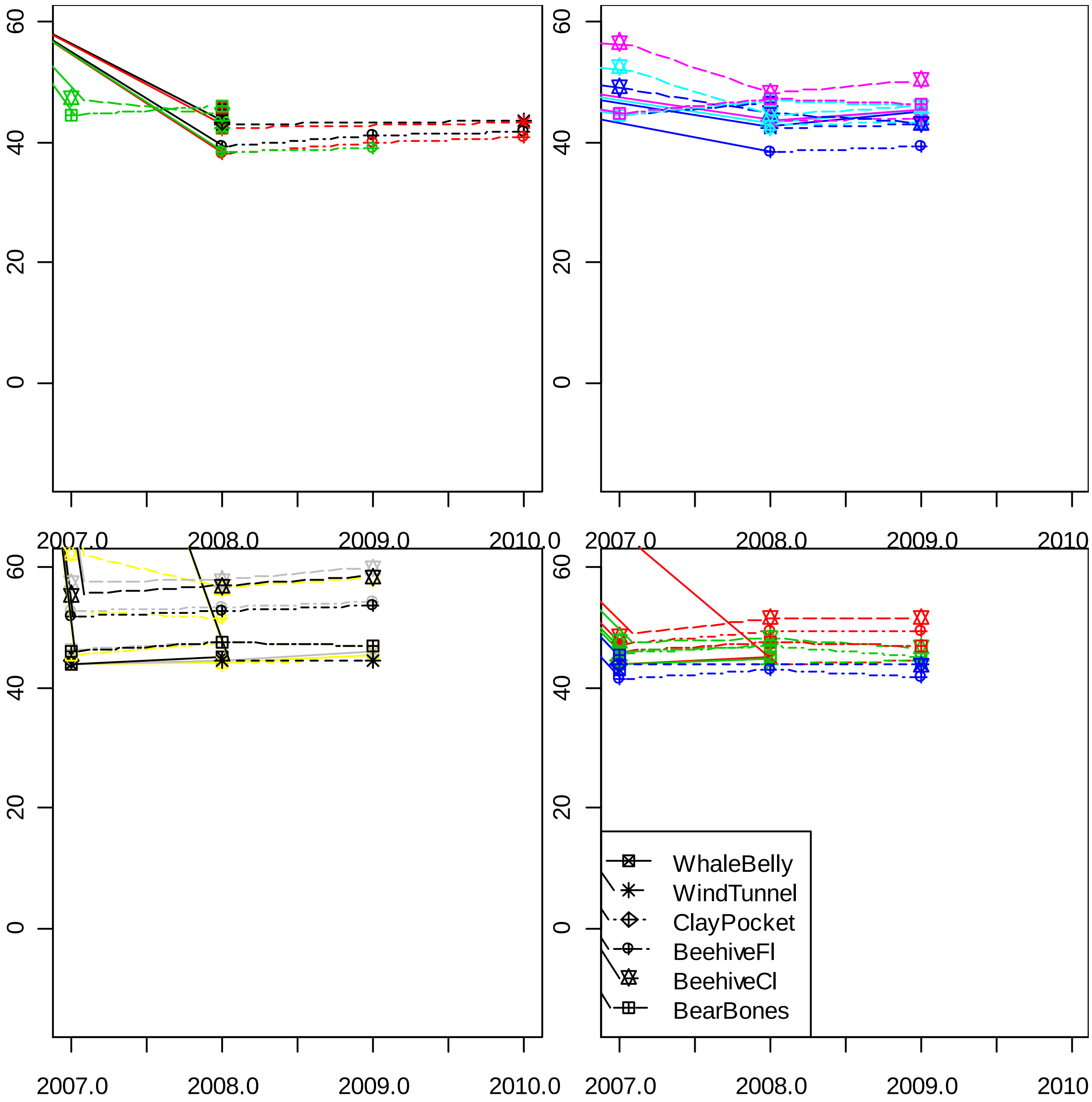






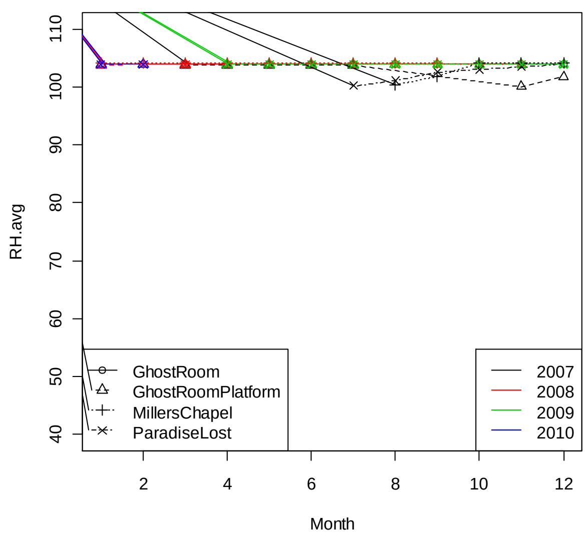
Monthly Time Trends for different locations: each month is plotted with a different color. Top left Jan-Mar; top right April-June; bottom left July Sept; bottom right Oct-Dec. A strong month effect would manifest as the colors separating out---they do not.

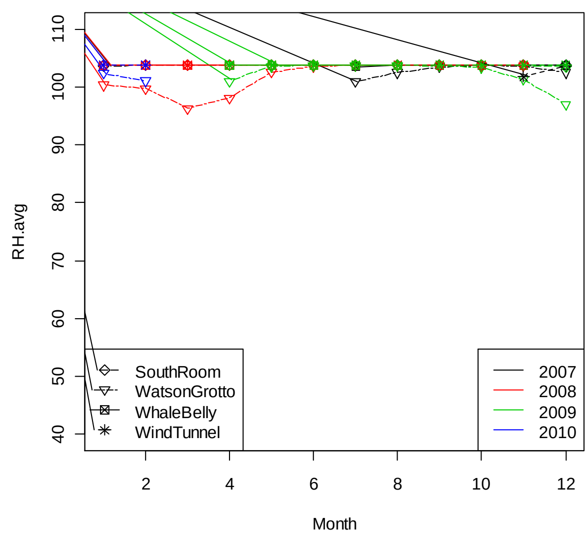


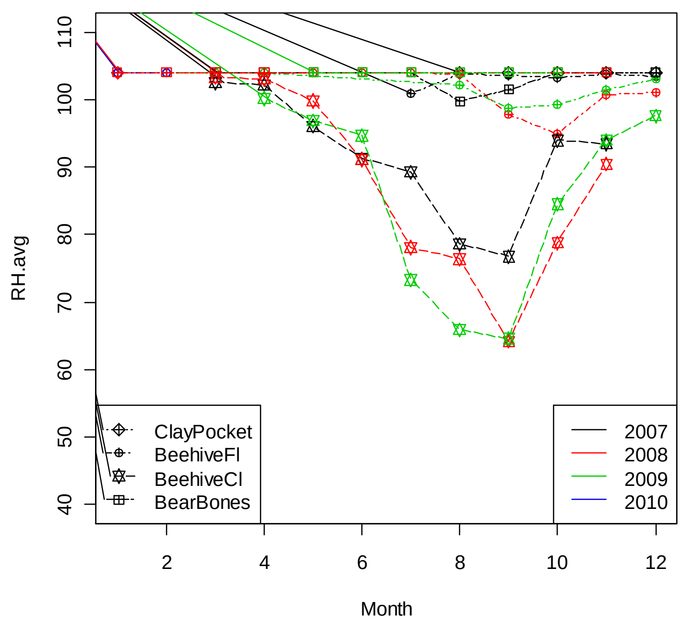

60
40
20
0
2007.0
2008.0
2009.0
2010.0
2010
WhaleBelly
WindTunnel
ClayPocket
BeehiveFl
BeehiveCl
BearBones

Relative Humidity

The Monthly averages (averaged over hours and days) for each location plotted for each year separately; there doesn't appear to be much month-to-month variability except for Beehive ceiling. The patterns are basically the same across the 4 years of data for all locations.

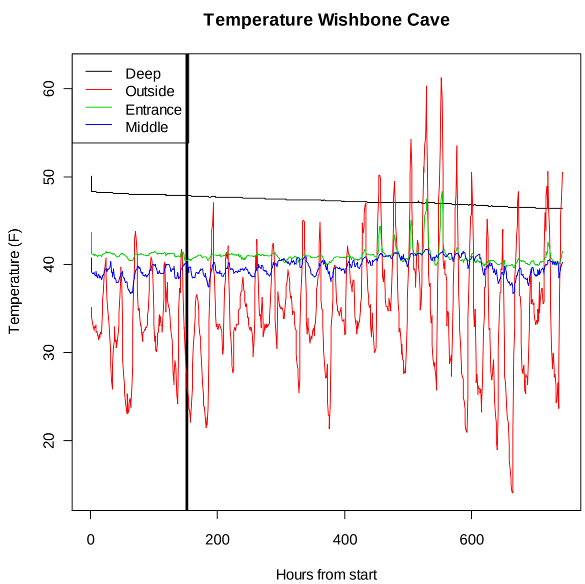


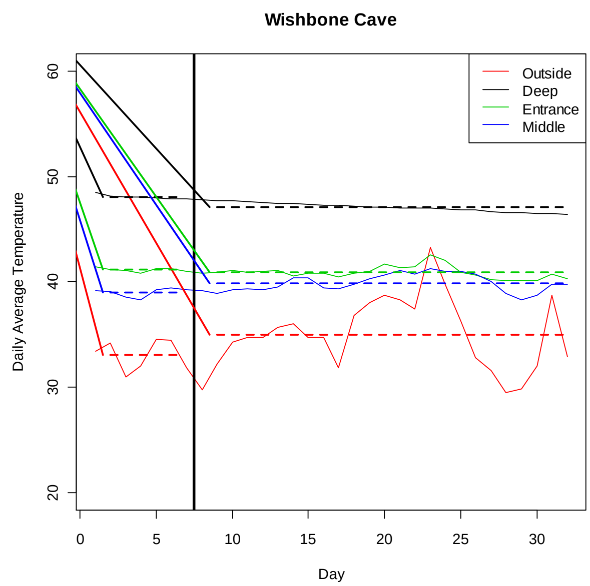


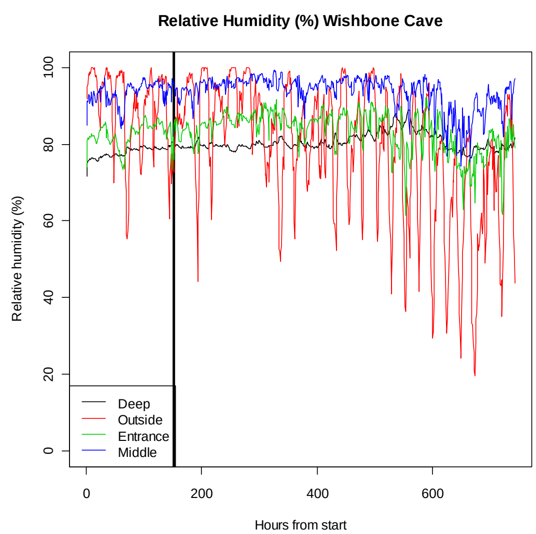


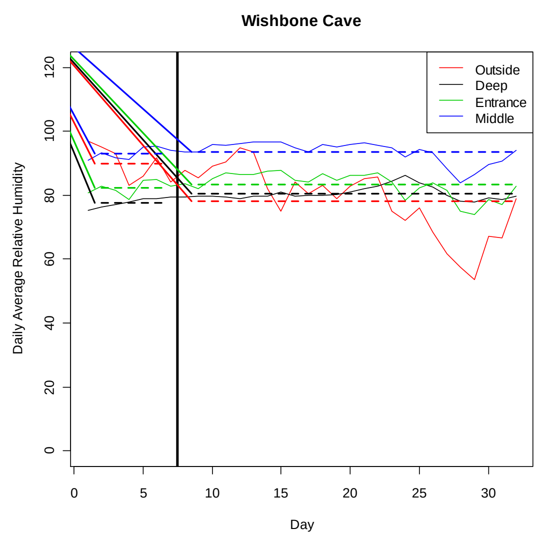
Appendix. LABE Climate Data Plots

Wishbone Cave

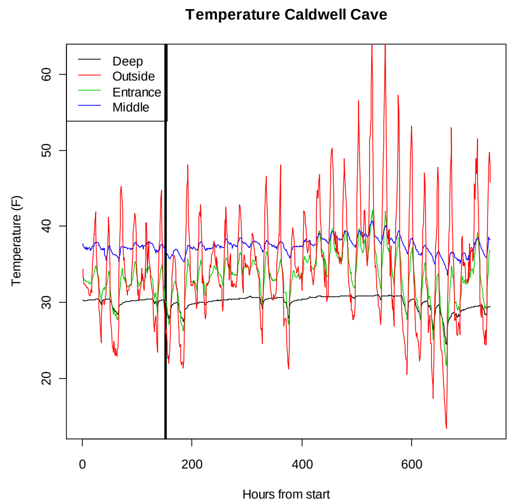


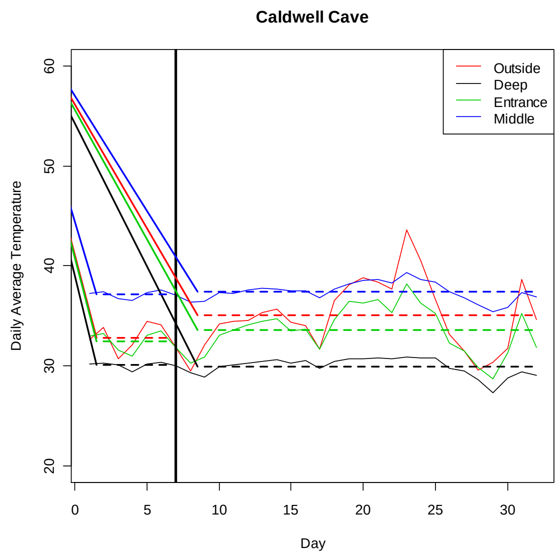


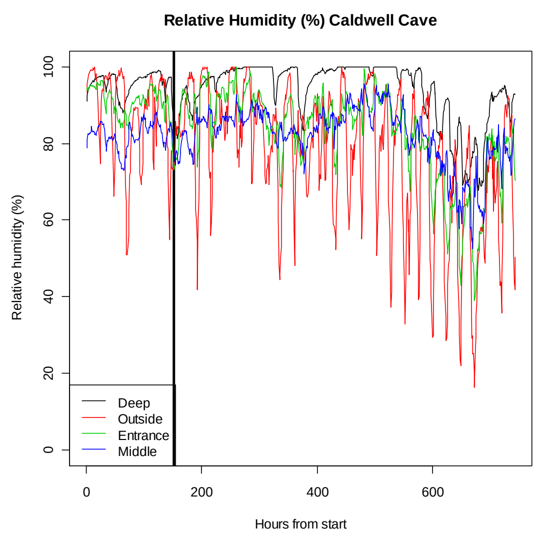


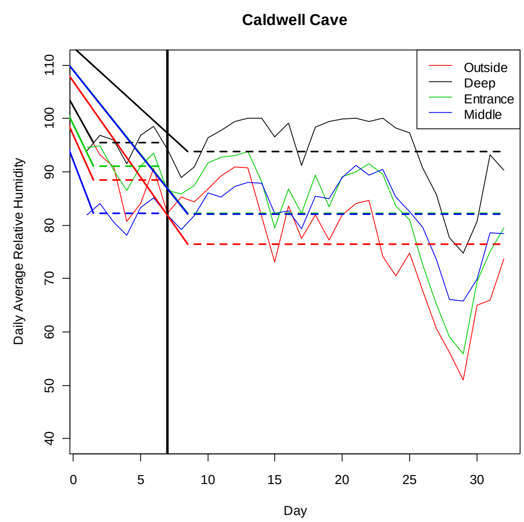


Caldwell Cave



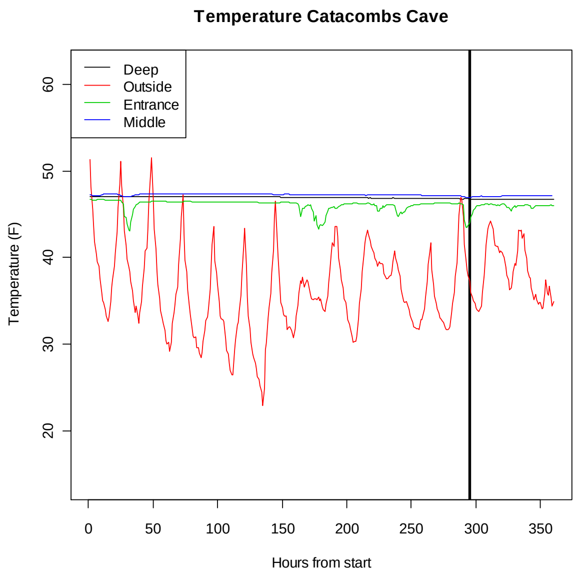


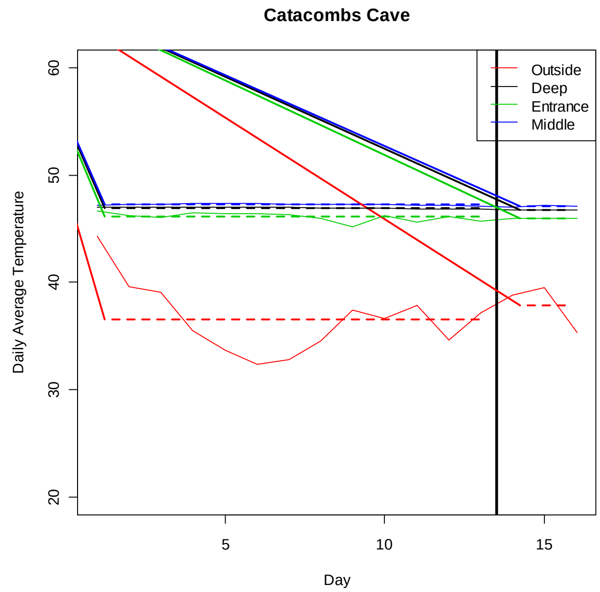


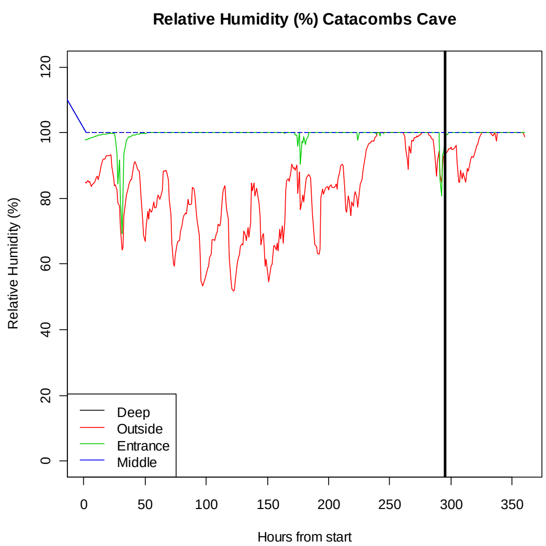


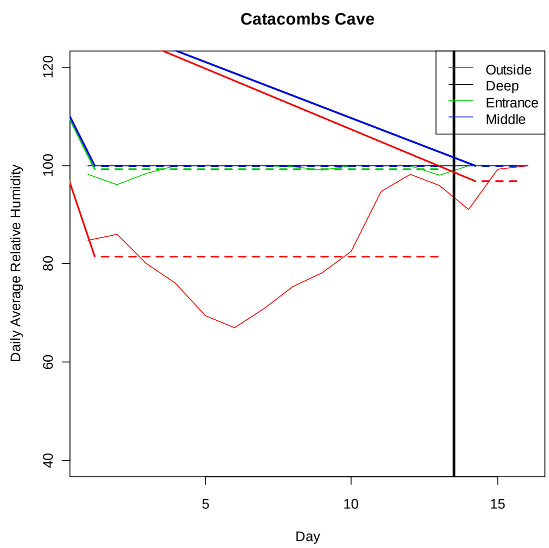
Feb and March- vertical line is division

Catacombs Cave

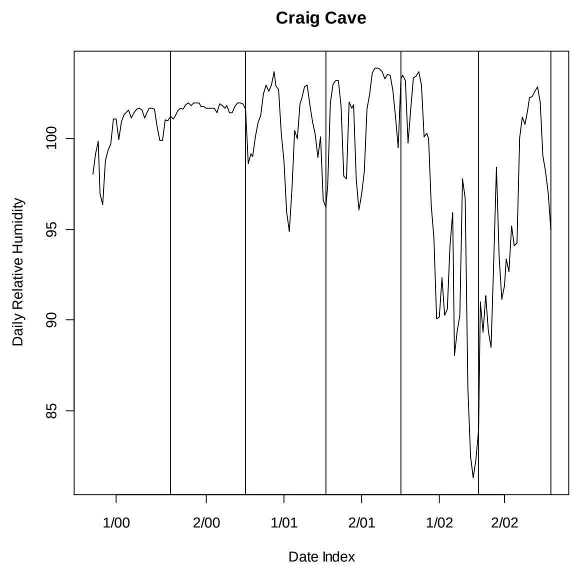


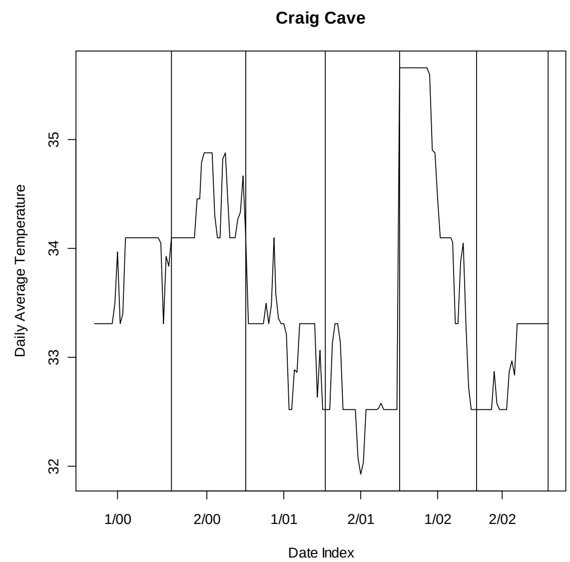




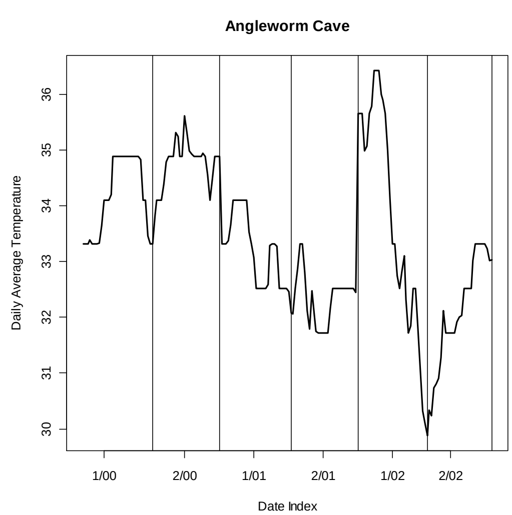


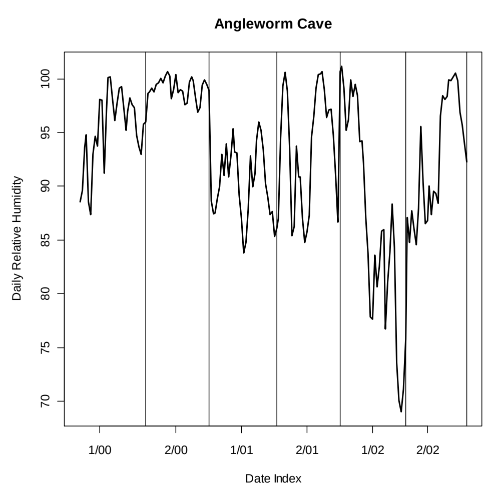
Craig Cave





Angleworm Cave





Weather Station